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Review

Analysis and comparison of used lubricants, regenerative technologies in the world

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ABSTRACT

Used lubricants can be an important resource for oil-producing countries. Lubricants are categorized as hazardous wastes as they contain high levels of environmentally toxic organic compounds such as PCBs, PAHs and heavy metals. A growing trend of regeneration and reuse of used lubricants has been seen in the recent years to supplement the conventional sources of energy. Thus, governments have focused on developing these recovery processes on an industrial scale. Evaluation of the individual techniques indicated that acid/clay process has the lowest cost and the highest environmental risk in comparison to the other regeneration technologies. Acidic sludge, a toxic by product of the formerly mentioned process, can be used as a raw material for production of economically valuable bitumen. The conversion is not only cost-effective, but it also reduces the environmental risk to a large degree. Economic indices and the quality of the obtained product showed that this process supports sustainable development.

Contents

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Nomenclature

PAHs	polycyclic aromatic compounds
PCBs	poly chlorinated biphenyls
PPM	part per million
L	liter
USEPA	United States Environmental Protection Agency
Cst	centistokes
TFE	thin film evaporation
TDA	thermal de-asphalting
MAFF	Ministry of Agricultural, Fisheries and Food
USDHPHSA	United States Department of Health and Public Health Service Agency
EU	European Union
USA	United States America
SBS	styrene–butadiene–styrene
ASTM	American Society for Testing Materials
PI	penetration index
PG	performance grade
D mm	deci millimetre
PVC	poly vinyl chloride
KWH	kilo watt hour
HP	horse power
EFQM	European Federation for Quality Management
KBEM	Kanji's Business Excellence Model
CSFs	critical success factors
Pa	pascal
API	American Petroleum Institute
DLC	diamond-like carbon
HP HT	high-pressure high-temperature
CVD	chemical vapor deposition
PVD	physical vapor deposition

1. Introduction

During the Second World War, deficiency of adequate supplies of crude oil persuaded the reuse of all types of materials as sources of fuels, especially the used lubricants. With technological progresses and the ever collapsing reserves of fossil fuels, more countries are getting back towards recycling used lubricants to afford their energy demands (Udonne, 2011). The demand of lubricating oil is increasing with the establishment of new industries, increase in number of vehicular transports and mechanization of agriculture and industries (Chaffai et al., 2001). Zhang et al. (2003) indicated that in the future, the motor oil price will increase, because the motor oil production cannot supply the demands due to global crude oil shortage. On the other hand, there is high consumption in the developed governments and population growth in the developing governments. That is why the consumption motor oil and production of used oil will increase in the coming years. Hence, the quantity of spent oil generated is huge and enormous and can be considered as a source of pollution or as a fuel resource depending on the utilization and management practices. It is estimated that 3.8 L of used oil can corrupt the taste of 3,800,000 L of drinking water and 50–100 PPM of used oil can hinder or postpone the wastewater treatment processes (Pramanik, 2003). Also, 1 L of used motor oil as a fuel has a caloric value of about 8000 kJ which can be used to light a 100-W bulb for a day or provide energy to a 1000-W electric heater for 2 h. Pawlak et al. (2010) reported that 3.8 L of used motor oil mainly can be regenerated into 2.3 kg of lubricating oil. Also, while 67 L of crude oil are requested to extract 1 L of motor oil, only 1.6 L of used oil is required to generate the same quantity of motor oil. The studies also showed that a 150 kg barrel of crude oil typically contains only 1.9 kg of lubricant-quality based oil (Sınag et al., 2010; Siddiqi and Anadon, 2011). Obtained results showed that many of the recovered oils were analogous to the crude oils in terms of their chemical composition and physicochemical properties (Hamed et al., 2002). However, the quality of regeneratd oil is better than that of the crude oil (Eman and Abeer, 2013). The efficiency of used lubricants recycling is about 75–60% and the price of the oil obtained from the regenerative technologies is equivalent to crude oil prices. In addition to this, recycled lubricant oil needs lesser energy compared to the lubricant oils derived from crude oil. Therefore, governments actually need to manage the used lubricating oils produced as a valuable matter (Eterigho and Olutoye, 2008). Hassanpour and Mohammadi (2012a) showed that the best management practice in order to supplement the energy from motor oil consumption is the recovery of used oil in Iran. Hamed et al. (2002) represented that in the Emirate of Sharjah alone, recycling used oil can thrift $168,000 per year in fuel, or 950,000 L of base oil as well as other benefits.

In current study, the term "used oil" relates to lubricating oils that are collected after usage in light and heavy automotives, vehicle engines, industrial and agricultural machines, etc. Used oil is not classified as a hazardous waste under USEPA unless it exceeds the limits in toxic and hazardous compounds such as chlorinated solvents (USEPA, 2005). Vorapot et al. (2009) has reported that total used lubricant oils are classified in the list F of hazardous waste materials. These compounds are produced from common manufacturing processes of industry or by products in synthesis of coolants, supportive components against corrosion, insulation, cleaners etc. These classes of compounds were previously called non-special source wastes. The industrial lubricants are normally classified based on their ISO grade and their viscosity in CSt at 40 °C. The currently used commercial lubricants encompass a range of ISO grades from <10 to >1000. Car motor oils are usually classified according to the SAE grade system and over the viscosity range of interest in the demand. Base oil may be obtained from various sources with crude oil being the initial commercial source. To enhance and promote the performance of lube oil, additives are combined with the base oil (Miller et al., 2007). Kheireddine and El-Halwagi (2013) showed consuming the additives increase the amounts of toxic aromatic components in the lubricating oils. The major difference between fresh lube oil and the used oil is the additives amounts to make contaminants up in the latter that will blend with light and heavy contaminants from inside the engine as well as the wearing metal interiors and dust, water and oxidative aromatic compounds.

With regard to environmental and health hazards (carcinogen) of used lubricating oils, existing numerous industries and huge volumes of used lubricating oils generated per day it would be interesting that they can be become to extremely valuable products as well as economic privileges, creating job opportunities, business and promoting the business excellence. However, the role of industrial sector for economic development and its priority for promoting and fortifying other sectors to establish and implement job and business opportunities is clear (Powell and Snellman, 2004). Fagerberg (2000) reported that growth and development of industries have an important and significant role to achieve stable and rapid economic growth and development with exports having a positive impact on the society. Sustainable development has been explained on the three aspects including, environmental performance, societal responsibility and economic assessments. Economic estimates of indices contain the impacts of the industry on the economic well-being, stakeholders and economic systems at all levels (Krajnc and Glavic, 2005).

Hsu et al. (2010a) have showed the scale and complexity of lubricant regenerative technologies. At present, there are many kinds of typical lubricant recycling technologies such as: (1) acid/clay process; (2) distillation process; (3) solvent de-asphalting, (4) TFE with hydro-finishing; (5) TFE with clay finishing; (6) TFE with solvent finishing; (7) solvent extraction hydro-finishing, (8) TDA with clay finishing and TDA with hydro-finishing. There are some differences among these technologies such as economic privileges, evolution and environmental impacts. Also, many modern technologies are being developed and requested continuously. Therefore, governments shall be responsible for analysis, technology assessment and processing the ideas of academia, industrial processes and government sectors to implement a measuring index for selection of used lubricants' regenerative technologies. On the other hand, disposal of acidic sludge produced by the formerly mentioned techniques as a secondary pollutant is a matter of greater environmental concern (Alhamed and Al-Zahrani, 1999). In this review, the various regeneration technologies and operation processes for used lubricants shall be discussed along with their advantages and drawbacks.

2. The classification of used lubricants

2.1. Clean used oil

This class contains the cutting and hydraulic oils. Processing of this oil type is performed by re-refining and laundering processes.

2.2. Mixed used oil with clean oil

These include hydraulic oil, hydraulic mineral oil and diathermic oils without chlorine rate. Processing of this oil type is regeneration or re-refining.

2.3. Mixed used oil

This includes all the oils that are not separated at the production source. Processing of this oil is by gasification. The oil is passed through plasma jet equipped with incinerators having temperature control, to produce oxygen-rich gases, hydrogen, carbon monoxide and other gases which are used in the industry itself.

2.4. Total used oils

The total oils that are not separated in the production source plus heavy base oil form the total used oil. There are three types of processing used for these oils such as intensive processing, soft processing and direct incineration.

2.5. Other used oils

Used synthetic oils are placed in this category. These are mainly processed by thermal cracking (Hsu et al. (2010b); Hassanpour and Mohammadi, 2012b; MAFF, 1999, 2002).

There is a classification for oily waste materials that set by USEPA. Oily waste materials are produced from the processing and using or maintenance of "mineral oils" (oil that is made from crude oil). Table 1 presents the classification oily waste materials.

Table 1
Classification the oily waste materials based on the (USEPA, 2005).

Oily waste materials	Process/industry type	Industry group
Used motor oil	Vehicle repair facilities, petroleum stations	G/L
Acidic oily wastes	Texture industry	H
Polluted fuel oils	Oil chambers	Different
Compressed materials in compressors	Compressors	Different
Concentrated materials	Supplying building materials, chemical	E
	Saving tanks	Different
Oily sludge containing cyanide	Cleaning of metal surface	G
Oily sludge	Recovery and cleaning	F
	Exploration Petroleum and Mines	C
	Petroleum refining	C
Tank bottom sludge	–	–
Thermal exchanger sludge and APJ separators sludge	–	–
Floating material in dissolved air floatation silt/runoff	–	–
Oily sludge	Coking unit and gas refinery	C
Caustic sludge	Process/industry type	F
Used emulsions in cutting and grinding	Vehicle repair facilities, petroleum stations	C
Waste vegetable oils	Texture industry	A

Table 2
Special limitations of used oil for incineration (MAFF, 2002).

Elements	Concentration (mg/L)
Lead	100
Arsenic	5
Chromium	10
Cadmium	2
Total halogens	4000–1000
PCBs	2
Sulfur	1

3. Disposal methods of used lubricants

Some of the main options which may be considered for disposal of used lubricants are reuse, thermal cracking and incineration. However, each one of these practices has certain limitations. Tables 2 and 3 represent the disposal limitations of used oils so that incinerating and mulching, respectively. The USDHPHSA (1997) has reported that the mulching method can be followed by observing the limitation of 0.19 L per 0.093 square meter the soil, twice per year for a period of twelve to twenty years. Also rotation cultivation maybe followed in ground treatment procedure. The soil pH

Table 3
Special limitations of used oil for mulching (MAFF, 2002).

Elements	Concentration (mg/L)
Lead	71
Arsenic	>0.5
Chromium	6.4
Cadmium	1
Total halogens	4000–1000
PCBs	>0.5
sulfur	0.4
Copper	100
Silver	1
Chlorine	184
Naphthalene	125
PAHs	204

Table 4
Production of lubricating oil, its collection and loss to the environment (Pawlak et al., 2010).

Country	Production	Collection	Loss to the environment
USA	4.5 Billion kg	2.6 Billion kg	660 Million kg
Australia	465 Million kg	180 Million kg	54–88 Million kg
EU	5 Billion kg	2.5 Billion kg	100 Million kg

can be controlled and these operations can be performed during 6 to 8 weeks of summer. Burning and all other routes of disposals of used lubricating oils are uneconomical and result in the wastage of resources. The recycling of used lubricating oils may be a suitable and economical alternative instead of burning (Katiyar and Husain, 2010; Venerando et al., 2009).

In the EU, about 25 companies participate with used oils recovery and have a total production of about 500 kt/y, with individual capacities ranging from 35 to 160 kt/y. Recovery typical processes are running in many countries like Germany (seven units), Italy (five units), France, Spain, Denmark, Iran, Poland and Greece. Currently, a wane trend in recovery capacities may be seen in some EU countries (France, Germany, and Italy). New units are establishing and implementing in a number of countries (France, Germany, Italy, and Spain). Two industries—Detox the Banska Bystrica and Konzeko Markusovce are active with used oils recovery in Slovakia. According to the many reports there are about 200 recycling units (small industries) of the used oil in Iran. Globally, there are about 400 recovering units with a total capacity of 1800 kt/y, in the USA, Canada, Tunisia and Saudi Arabia. Most of these units have been located in East Asia (India, China, Pakistan). The majority of these units utilize by acid/clay process and only a few of them observed and heeded to environmental protection (Jonidi and Hassanpour, 2013a; Willing, 2001; Yoon et al., 1999).

Jonidi and Hassanpour (2013a) estimated the disposal rates of used oil by common methods like incineration with and without reuse energy, landfill, saving, reuse and reprocessing to be 37, 3.7, 18, 1, 21.17 and 69.8%, the landfill and reprocessing rates 18.87 and 81.13%, 8.1 and 91.88 in England, Scotland and Ireland, respectively, in 2002. The collecting level has been mentioned to be 65, 52, and 75% in Australia, Europe and US in 2002. Lengyel et al. (2009) showed that the rates of collected oils arrived about 50% of the consumption oils, of which about 30% were utilized for energy production, about 30% were converted to base lubricating oils, about 25% were applied to industrial fuels and about 10% encompass cleaning to yield special industrial oils in 2009. California annually generates more than 495 million kg of used oil and the recovery rate has been estimated about 59%. In California, USEPA permits

Table 6
List of common additives used in lubricating oils (MAFF, 2002).

Common additives	Example (s)
Friction modifiers	Boron nitride, graphite
Anti-wears	Esters, chlorinated paraffins
Rust and corrosion inhibitors	Organic acids, alkaline compounds
Anti-oxidants	Alkyl sulfides, hindered phenols
Detergents	Phenolates, sulfonates
Dispersants	Hydrocarbon succinimides
Pour point dispersants	Co-polymers of polyalkyl methacrylates
Viscosity index improvers	Acrylate polymers
Anti-foaming	Dimethyl silicones
NANO-particles and composites	Diamond and etc

the combustion of used oil generated by heaters. The recovery rate has been estimated about 94% in Taiwan in 2010. Australia annually generates around 465 million kg of crude lubricant oils and collection rate is about 180 million kg, about 54–88 million kg is refused to the environment. Currently, the rates of collected lubricating oils have been estimated about 2.6 billion kg per year in the USA. According to the some reports about 83% of this rate is burned and 17% is regenerated, but in the EU these rates are 77% and 33%, and in Australia 97% and 3%, respectively (Pawlak et al., 2010). Tables 4 and 5 represent the production of lubricating oil, its collection, loss to the environment and its recovery in the US, EU and Australia respectively in some studies. These rates are not clear in Iran.

4. Additives and pollutants

Over the last century, an increasing range of additives has been incorporated into lubricating oils to achieve chemical stability, enhance performance and fortify physiochemical properties. Ribeiro et al. (2007) have reported that the additives enhance ignition and combustion efficiency, stabilize fuel content, protect the motor against corrosion, oxidation, friction, abrasion and deposition, and abatement pollutant dissemination as well as other advantages. Recently, the nano-materials are discussed in order to add into oil and lubricants to confer friction reduction and increase longevity (Girotti et al., 2011). Table 6 is a list of the most common additives used in the lubricant oils.

A barrel of used oil includes 1–15% water as free or emulsion, 1–5% light hydrocarbons, 60–90% recoverable rate and 7–20% additives and contaminants. The important source of oil contamination during use is the chemical disrupt of additives and their interaction to generate corrosive unfavorable components. PAHs are of main concern due to their known carcinogenicity. However,

Table 5
Recovery rate of lubricants in European regions (Hsu et al., 2010b).

Region	Consumption (*t*)	Predicted recoverable rate	Predicted recovery (*t*)	Actual recovery	Recoverable rate (%)
Austria	102,400	44	45,000	33,500	74
Belgium	173,608	44	76,388	60,000	79
Denmark	71,416	65	46,420	35,000	75
Finland	89,194	54	48,165	38,532	80
France	888,771	49	435,498	242,500	56
Germany	1,076,149	50	538,075	460,000	85
Greece	88,000	68	60,000	22,000	37
Ireland	38,900	51	19,839	17,062	86
Italy	681,100	40	272,440	200,395	74
Luxemburg	10,150	50	5075	2000	39
Netherlands	154,685	54	83,530	60,000	72
Purtugal	113,200	55	62,260	39,620	64
Spain	496,141	55	223,263	105,000	47
Sweden	146,847	54	79,297	63,438	80
Great Britain	803,667	51	409,870	352,500	86
Europe	4,934,228	49	2,405,120	1,731,546	49

Table 7
Contaminants of potential concern in used oils (El-Fadel and Khoury, 2001).

Organic contaminants	Probable source	Concentration (μg/L)
Aromatic hydrocarbons		
Polynuclear (PNA)	Petroleum base stock	
Benzo (a) pyrene		360–62,000
Benzo (a) anthrcene		870–30,000
Pyrene		1670–33,000
Monoaromatic		
Alkylbenzenes		900,000
Diaromatic		
Naphthalenes		400,000
Chlorinated hydrocarbons		
Trichloroethylenes	Chemical reactions	18–1800
Trichloroethylene	During use of waste	18–2600
Perchloroethylene	Oil	3–1300
Metals		Mg/kg
Barium	Additives package	60–690
Zinc		630–2500
Aluminium	Metal wear	4–40
Chromium		5–24
Lead	Leaded gasoline	3700–14,000

contents of pollutants depend on several parameters including type of original detergents, added diluents, storage circumstances and management and utilization practices. For example, pay attention to recede use of leaded gasoline, consequently the lead concentrations in used oil will decrease significantly, therefore the necessary concentration of bromine and chlorine additives will also decrease, additional reducing the occurrence of halogenated hydrocarbons in used oil (Diphare et al., 2013; El-Fadel and Khoury, 2001). Table 7 shows the contaminants of potential concern.

5. Re-refining or regeneration technologies

The selection of regeneration technologies to be used for used lubricant oils depends on various criteria such as (1) Technology (operating temperature, recovery quantity, products quality and process development stage), (2) The economic aspects (water costs, total required energy costs, unit scale, equipment costs) and (3) The environment protection (PCBs removal, acidic sludge generated, residual oil sludge, hazardous chemical substances used). Nowadays, there are many regeneration technologies to generate lubricating oil for reuse. The operational framework of all technologies encompass the following four steps, (1) Dewater/defuel; in the use of lubricating oil, foreign components are combined into it depend on different conditions; moisture is penetrated into the lubricating oil in a long-term service. On the other hand, the fundamental compounds of light fuel are fuel and naphtha, main source from these compounds are leakage of fuel for vehicle motor to the lubricating oil and the deterioration of compounds of lubricating oil. These foreign components should be segregated based on the difference between their physical properties and the lubricating oil. (2) De-asphalt; there are solid foreign components such as metal powder derived from mechanical wear and additive added in during operation. The most important point to eliminate this type of pollutants is the different physical properties such as different solubility and boiling points. Totally, de-asphalt is fulfilled mainly by adding in sulfuric acid, solvent treatment method and film separation or heat treatment. (3) Fractionation; the fractionation classifies different materials based on boiling points of components to select or eliminate a specific sort of materials. (4) Finishing; the final treatment is carried out to eliminate some foreign components, like chlorine, nitrogen, oxygen, and sulfur, which cannot be eliminate through the mentioned steps. Clay or hydro-treatment is often requested for the finishing step. Among these technologies the important difference is the de-asphalting and the finishing procedure (Guerin, 2008; Hsu et al., 2010b).

The latest available technology, TFE, has three different processing trends based on different finishing trends, such as TFE with clay finishing, TFE with solvent finishing, and TFE with hydro-finishing. TDA is in addition to the latter procedures. On the other words, the physicochemical technologies used to regenerate lubricants include vacuum distillation with clay, chemical material-finishing (i.e. thermal, chemical materials, solvent or clay or integrated methods) and vacuum distillation with hydro-finishing. The distillation process depends upon the process type, pollutants concentration of used lubricants and requirement product quality as vacuum distillation, heating or preliminary distillation and TFE (Hani and Al-Wedyan, 2011). TFE are generally used in America and Europe but the other methods, especially the acid/clay technology are utilized usually in the developing governments. Reuse of the used lubricants is performed using re-refining process. The re-refining of used lubricants is used when they contain high concentrations of contaminants. This process yields by-products that find their use as fuel. Thus, the re-refining processes used for the treatment of used lubricants have a marked influence on the pollutants concentration and the applied product quality (Guerin, 2008). The operational processes of all technologies encompass the following has been explained.

6. Operational processes from used lubricants regenerative technologies

6.1. Acid/clay process

In this process, after dehydration and distillation of used lubricant oil, re-refining or reprocessing operation is done using sulfuric acid. Clay is used to remove certain impurities. The acid/clay process has minimal environmental safety. The main by-product of this process is the large amounts of acidic sludge. Based on the concentration of contaminants, the type of lubricant oil and the regenerated oil quality, this process can be as a reprocessing or regenerative method. These two methods are different in terms of the heating rate (distillation unit) and the generated by-products (Ogbeide, 2010; Hsu et al., 2010b). According to the report of Iranian industry organization, more than 200 reprocessing units (acid/clay process) of used motor oil are currently active in Iran (Hook et al., 2009; King et al., 2005). Acidic sludge is a by-product from acid/clay process which is regarded as hazardous waste material base on USEPA list. Jonidi and Hassanpour (2013a) showed that decreasing the volume of acidic sludge with eco-friendly methods can be an appropriate management process. The limitation of this method is the lack of sufficient scientific information in this field. These techniques apply sophisticated sciences and complex technologies. Other management that has practices worth a mention is the acidic sludge incineration and the utility of the energy obtained from combustion (Hassanpour et al., 2013). Thermal value of acidic sludge incineration is calculated to be about 4000 kcal/kg. Acidic sludge basically encompasses unsaturated compounds, which are polar and asphaltene. Acidic sludge composition is analogous to bitumen. Bitumen encompasses hydrocarbons with high molecular weight such as oil, resin and asphaltene (Mohammadi and Hassanpour, 2011a; Kavak et al., 2010; Sadraddini et al., 2002). Hassanpour et al. (2014) reported that the environmental and health hazards of acidic sludge can be decreased by its modification and neutralization. Also, for it to be used as the prime raw material in the production of bitumen, acidic sludge has to be modified or amended in one way or the other. In the physical modification, acidic sludge is mixed with additives like bentonite, polyethylene, ethylene vinyl, ethylene vinyl acetate, SBS and other forms of these polymers as well as nano-composites and nano-particles (Shahabadi et al., 2010; Williams, 2005). The observations and findings of Jonidi et al. (2014)

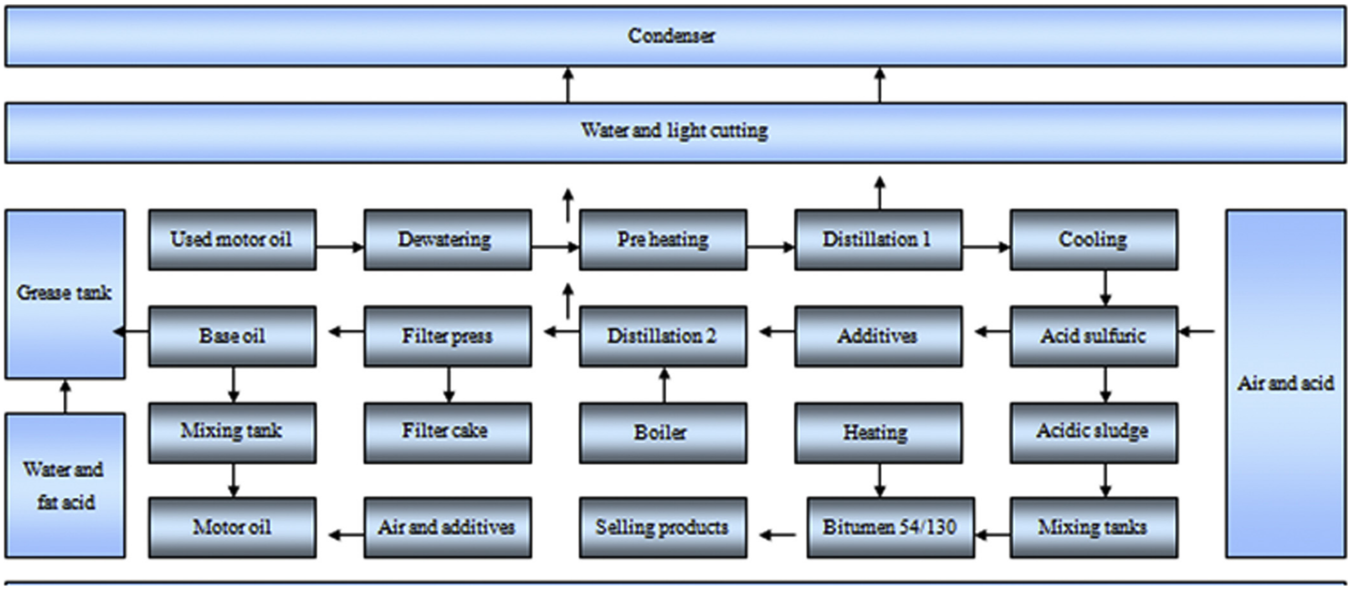

Fig. 1. Diagram of layout acidic sludge recycling units and reprocessing industry of used oil (Jonidi et al., 2014).

Table 8
Performance parameters of acidic sludge recycling (ASTM, 2000).

The properties of bitumen	The optimal properties of bitumen for climatic conditions of Iran	Jonidi et al. (2014)
Softening point (°C)	20 to 85	54
Weight loss %	1	1
Penetration degree (dmm)	30 to130	130
PI	−2 to +2	0.5774
Frass breaking point	−12	−11
PG	Different	Different

have been summarized in Table 8, for the production of bitumen 54/130 from acidic sludge. The obtained products could also be utilized in building and road construction according to its specific bitumen criteria and characteristics (Ouyang et al., 2005; Kok and Çolak, 2011). In the study, acidic sludge was a by-product of used oil reprocessing industries which was disposed into the environment as hazardous waste material. Fig. 1 represents a diagrammatic layout of acidic sludge recycling units and reprocessing industry of used motor oil.

Eterigho and Olutoye (2008) showed that the acidic sludge could be converted to the valuable products and raw materials for the synthesis of compounds such as organic fertilizers, explosives materials, paint, ink, chemical fibers and industrial detergent. Processing of acidic sludge generates different commercial products such as surfactants, sulfuric acid, light hydrocarbons, coke, activated carbon, furnace fuels, different types of bitumen and asphalt, thermal insulators, etc. Acidic sludge can be used as an additive in bitumen materials and in the preparation of carbon rods. Based on the technical studies conducted by the Iranian industrial organization, bitumen materials can be used as raw material or as additives in the industrial production of a wide variety of essentials such as wool fibers, books and booklets, laminated paper envelopes, asphalt heat insulators, plastic bags, automotive fan belts, PVC floorings, proof insulated pipe covers, blown bitumen, emulsion bitumen, polymer bitumen, motorcycle battery, paint, ink, printing ink, liquid bitumen, etc (Jonidi et al., 2014).

Santos (1994) patented a process for converting the acidic sludge, produced by used oil refineries, into an intermediate sludge which can be used in the production of either soft, un-oxidized or hard, oxidized asphalt. The acidic sludge obtained from oil refineries is not biodegradable in nature and is about 30 to 50% soluble in water. In used oil refining process, the acidic sludge is approximately 5% by volume of 98% sulfuric acid and has a pH less than 2, typically a pH of 0.1. Consequently, this acidic sludge is highly acidic and toxic. The volume of acidic sludge produced is approximately 0.95 L per 3.8 L of used oil. There are prior industrial processes which combine acidic sludge with other compounds to produce asphalt. Various additives may be added to alter the characteristics or improve the quality of the resulting asphalt. Table 9 shows some of the patents in the field of reprocessing and regeneration technology.

Jonidi and Hassanpour (2014) showed economic indices of the reprocessing industry equipped to acidic sludge recycling unit (The breakeven point about 6% and the time of return on investment about 0.26 (3.2 month)). The economical point of view, the indices values such as value-added percent, annual income, breakeven point, value-added were demonstrated for the acidic sludge recycling process by Jonidi et al. (2015). The low breakeven point of about 14.7% and the time of return on investment 1.05 (about 13 months) demonstrated the fiscal success of this project. Further validation comes from the research of Iranian industrial organization which shows that low breakeven point of about 22.5% and the time of return on investment 0.9 (about 11 months) implied economic success of project for used motor oil reprocessing industries without acidic sludge recycling unit. Tables 10 and 11 show the results of studies. The acidic sludge recycling unit is generally within or next to the recycling units of used motor oil. In the afore mentioned studies by Jonidi et al. (2015) the working hours of the personnel was determined to be 270 working days per year with a shift of 8 h. Treatment capacity of used motor oil was estimated to be about 100 barrels (220 L) per day, 15% of which was acidic sludge. The required electrical energy (kW h) and water were calculated for 300 working days per year. The required water was calculated to be 3 L/m^2—green space and 100 L/person for a day. Total water required for the firefighting and safety purpose was calculated by a factor of 1.5. The staff salaries were calculated for a period of 14 months, with 23% of total staff salaries for insurance costs and pensions and a cost of $ 100 per month for transportation. Due to the low cost of working capital, the percentage of the worker's salary going for the payment of loans was neglected. Finally, economic

Table 9
Patents related with the topic (Uspto.org).

Title	Name	Data publication	Patents
Process for reclaiming spent motor oil	Company	1977	US4029569
Sulfonic acid source, sulfuric acid sludge	Schneider G L	1980	US4238241
Converting acid sludge to intermediate sludge in refineries	Santos B S	1994	US5288392
Bitumen production of acidic sludge from reprocessing industries	Jonidi et al.	2012	Iran 75360

Table 10
Requirements of used oil reprocessing industry (Jonidi and Hassanpour, 2014).

Main annual material and equipments	Total annual rates	Total cost $
Acidic sludge	891 m^3	–
Bentonite soil	330.32 t	103.225
SBS polymer	35.64 t	66,825
Barrels (220 L)	4050 Number	36,450
Used motor oil	5770 m^3	1,154,000
Acid sulfuric	411.3 t	154,237.5
Cao	22.5 t	1406.25
Additives as polymer for base oil	66 t	144,375
Fat acid	112.5 t	249,600.5
Drums 4.5 L for motor oil	700,000 Number	284,375
Drums 1 kg for grease	787,500 Number	123,046.8
Boxes with 24 empty spaces for grease	34,453 Number	10,766.6
Boxes with 6 empty spaces for motor oil	122,500 Number	15,312.5
Bitumen 54/130	891 t	417,656.25
Motor oil	3000 t	4,687,500
Grease	750 t	703,125
Required energy for heating of mixing tanks to 180 °C and distillation tanks	60,324,098 kJ	Supply by by-product
Required electrical energy	287,820 kW h	3598
Required water	16,980 m^3	1171.6
Water supply facilities		15,625
Split AC (Internal wiring, transformers and emergency power generators)		13,125
Fire extinguishers (total)	54 Number	3402
Stoves (total)	9 Number	270
Cooler (total)	8 Number	240
Ventilation system (total)	14 Number	280
Office equipment, furniture and etc		2500
Lab equipments (for the oil and bitumen quality control)		5000
Transportation (a vehicle weighing 4 t, car and fork)	7 Number	85,000
Staffs salary (33 persons)	33 Persons	110,000
Required fuel (stoves)	2360 L	332
Petroleum expenses (Transportation vehicle and cars)	44,400 L	9712.5
Required land	20,000 m^2	100,000
Construction of infrastructure (buildings)	2284 m^2	228,400
Pavement and asphalt	5542 m^2	53,688
Landscaping	2000 m^2	2000
Ground tank 2 × 15 × 12	1 Number	28,000[a]
Mixing tanks equipped with heating to 180 °C	2 Number	3150[a]
Propeller mixers with power 3.5 hp	5 Number	945[a]
Sewage pumps with power 10 hp	2 Number	840[a]
Stainless steel vacuum pumps with power 7.5 hp	4 Number	1260[a]
Gear pumps with power 5.5 hp	13 Number	2730[a]
Condenser	4 Number	840[a]
Sedimentation tank 20 m^3	7 Number	26,250[a]
Distillation tanks	4 Number	104,864.55[a]
Mixing tanks	5 Number	12,796.87[a]
Grease cooking chamber	1 Number	3062.5[a]
Filter presses with 20 blades (62 × 62)	1 Number	17,187.5[a]

[a] With 5% cost of installation.

Table 11
Economic indices (Jonidi and Hassanpour, 2014).

Economic indices of the used motor oil industry equipped to acidic sludge recycling unit	Cost $
Data value	
Grease	703,125
Bitumen 54/130	417,656.3
Motor oil	4,125,000
Total value of annual selling of products	5,245,781.3
Output value	
Additives, barrels and required materials	2,240,498.4
Maintenance	1624.075
Energy consumption	14,814.1
Unforeseen costs of fixed capital	33,049.43
Total cost	2,289,986
Value-added	2,955,795.3
Value-added percent	56.34%
Profit	2,795,396.8
Variable cost of good unit	535
Breakeven point (6%)	260.83
Production cost	2,470,258.36
Annual income	2,775,522.94
Time of return on investment	0.26 (3.2 month)
Economic indices of recycling acidic sludge project of reprocessing industries to bitumen	
Data value (value of annual selling of the product: bitumen)	417,656.25
The total production price	163,248.9$
Output value	
Additives and barrels	108,843.75
Maintenance	8214.77
Energy consumption	7407.125
Unforeseen costs of fixed capital	8055.85
Value- added	285,134.75
Value- added percent	68.2%
Profit	249,552.5
Variable cost of goods unit	141.8
Breakeven point (14.7%)	131.4
Production cost	169,285.7
Annual income	248,370.5
Time of return on investment	1.05 (13 months)
Economic indices of used motor oil industry (Iranian industries organization, 2000)	
Value- added	73,941.8
Value- added percent	36.3%
Breakeven point (14.7%)	22. 5%
Production costs	–
Annual income	–
Return time on investment	0.9 (11 months)

evaluation was performed using empirical Eqs. (1)–(11) and professional experiences (Santana et al., 2010; Wiedmann et al., 2006).

$$Q = MC'T \tag{1}$$

$$W = 0.75\left(\sum e\right) \times A \tag{2}$$

$$C = 0.005 \times P \tag{3}$$

$$V = p - \left(\left(\sum\right) e + A' + F + C_f\right) \tag{4}$$

$$\%V = V \times \frac{100}{p} \tag{5}$$

$$Q_p = V - \left(\left(\sum\right) I + L + D + S\right) \tag{6}$$

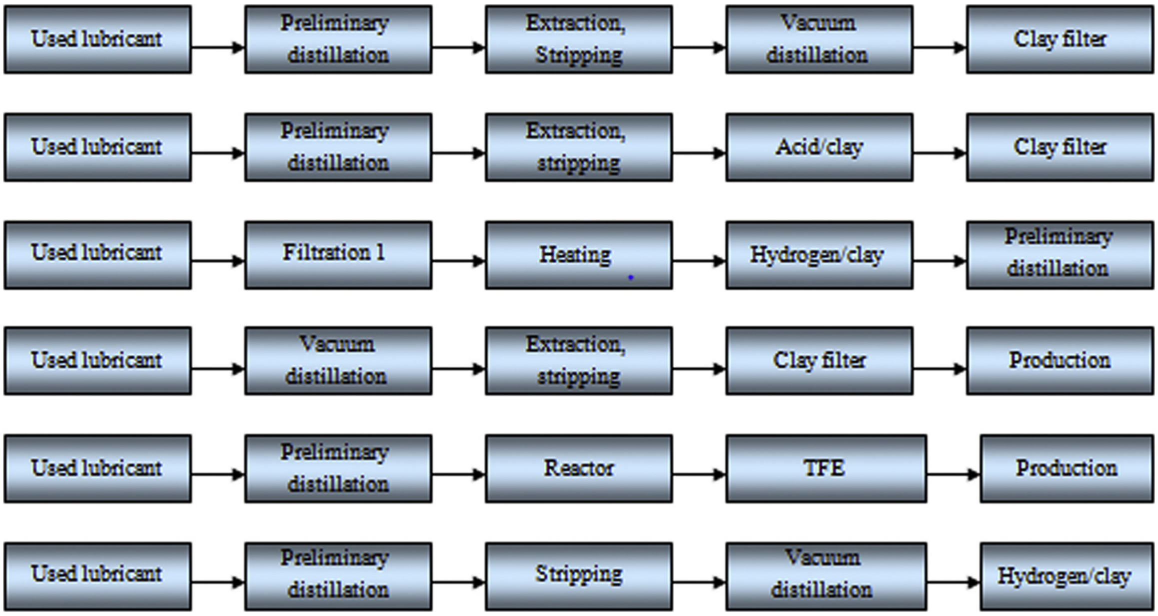

Fig. 2. Layout of various industrial and semi-industrial processes from regeneration lubricants in the world, these are operation processes from Bartlesville (industrial), solvent extraction (industrial) in Europe, Phillips (semi-industrial or pilot stage) process, RTI (industrial) in Norway, Recyclon process (industrial), KTI in America, respectively (Beg et al., 2010; Hamad et al., 2005; Durrani, 2010). In this figure, the number 1 is filtration to eliminate metals; and extraction and stripping are related to solvent.

$$C_v = \frac{C_{\mathrm{vd}}}{C_p} \quad (7)$$

$$P_h = \frac{T_f}{C_v - C_s} \quad (8)$$

$$C_{\mathrm{pi}} = C_{\mathrm{vp}} + C_{\mathrm{fp}} \quad (9)$$

$$A_i = T_s - C_{\mathrm{pi}} \quad (10)$$

$$V_t = \frac{I_f}{A_i} \quad (11)$$

In Eqs. (1) to (11), Q, M, C', T, W, e, A, C, P, V, A', F, C_f, Q_p, I, L, D, S, C_v, C_{vd}, C_p, P_h, T_f, C_s, C_{pi}, C_{vp}, C_{fp}, A_i, T_s, V_t and I_f, are the required heating rate (kJ), flow rate (m^3/h), thermal capacity, temperature (K·), required electrical energy, sum of electrical energy consumption (facilities, manufacturing line apparatus, building and campus), area (m^2), selling costs, selling price, value-added, initial materials (Additives and barrels), maintenance, unforeseen costs, profit, insurance, cost of interest and fees, depreciation, salary, variable costs of good unit, variable project costs, production capacity, breakeven point, total fixed costs, selling cost of good unit, manufacturing costs, variable manufacturing costs, fixed manufacturing costs, annual income, total selling price, time of return on investment and fixed capital respectively (Tainer, 2005; Cutler, 2005). The requirements of used motor oil reprocessing industry capital cost have been calculated from the data of DACE price book (DACE, NAP DACE, 2012 Dutch Association of Cost Engineers), edition November 2012.

In the similar researches on the economic assessment were published by Van Kasteren and Nisworo (2007) showed that biodiesel can be sold at US$ 0.17/L (125000 t/yr), US$ 0.24/L (80,000 t/yr) and US$ 0.52/L for the smallest plant capacities (8000 t/yr) with the existing alkali, acid catalyzed and a supercritical trans-esterification process. Zhang et al. (2003) showed that for three biodiesel plants with capacities 100,000 (1994), 7800 (1996) and 10,560 (1999) t/yr the breakeven prices in $/ton were 340,763, 420, respectively which used both alkali- and acid-catalyzed processes with waste cooking oil as the raw material. Among the studies conducted on the economic cycle of industries in Iran Moosavi and Rajabi (2013) were reported that the value-added will increase almost equal to the average annual growth rate of 18 percent for industries sector since 2009 to 2025 in Iran. Nelson et al. (2006) which dealt with the four indicators of water quality (sediment yield, surface runoff, Nitrate in surface runoff and edge-of-field erosion), the Switchgrass grown on the cropland in Delaware basin in Kansas had a production between 527,000 and 1.27 million metric tons of Switchgrass per year. The break-even price for Magnesium was calculated to be around $ 41 without used nitrate and slightly less than $ 25 at 224 kg of used nitrate per ha K h^{-1}. Thus, the produced Switchgrass had a break-even price of $ 30 Mg^{-1} or less.

On the other hand, Table 12 shows the results of a case study was published by Hassanpour (2014) in a used oil industry using business excellence models. These models allow multi-dimensional views on different aspects of the organization's internal, external and CSFS that include the required activities to get the industry or company objectives and key motors of performance (especially in

Table 12
Comparison of scores system in the used oil industry (Hassanpour, 2014).

KBEM		EFQM	
Criteria	Score	Criteria	Score
Leadership	90.33	Leadership	90.55
Satisfy the citizen and customers	77.5	Policy and strategy	87.7
Satisfy the external customers	60	Employees	85.83
Satisfy the internal customers	60	Resources and partnership	90
Fact-based management	74.16	Process	81.66
Process or total work	80	Customer results	78.33
Measurement	60	Employees results	73.88
Management relies on employees	70.41	Community results	70
Team work	98	Key performance results	49.42
Employees make quality	70	–	–
Continuous improvement	70.4	–	–
Continuous improvement cycle	70.8	–	–
Prevention	80	–	–
Business excellence score	768.2	Business excellence score	806.77

Table 13
Regenerative technologies comparison in terms of economic costs (Hsu et al., 2010b).

Regenerative Technologies	Energy requirement	Recycling rate (%)	Quality of regenerative oil	Economic costs
Acid/clay	Low	63	Good	Low
Distillation	High	50	Good	Low
Solvent de-asphalinting	High	70–65	API	High
TFE with hydro finishg	High	72	API	High
TFE with clay finishing	High	72	API	High
TFE with solvent finishing	High	72	API	High
Solvent extraction hydro-finishing	High	74	API	High
TDA	High	74–77	API	High

KBEM). The EFQM has been based on the assumption that excellence of industries and companies are obtained through leadership driving policy and strategy that are delivered through people, partnership, resources and processes. In order to study CSFS and different items together were used multiple weighting systems. Every one of criteria of the EFQM must be matched with two dimensions of KBEM. On the other hand, every one of KBEM items has a worth equal with 50 scores in EFQM. Therefore, in the obtained system were added 900 scores for criteria in EFQM until KBEM be enable to investigate organizational excellence in a diagram. The models criteria, factors and obtained results indicated that the industry was in sustainable development conditions.

6.2. Distillation process

This process is to fortify the purifying effect by using vacuum distillation (for re-refining or regeneration technologies) or preliminary distillation, heating (for reprocessing technology) prior to treating the used oil by using the acid-clay process, and the rest of operation flow is analogous to the acid-clay process (Fig. 1).

6.3. Solvent de-asphalting process

The solvent is used to segregate insoluble and suspended substances such as asphalt, metallic compounds and resin in the used oil. The process is analogous to the aforesaid two processes extra steps are solvent extraction and solvent stripping. Organic solvents, such as propanol and supercritical ethane can also be used for the solvent de-asphalting process (Rincon et al., 2003).

6.4. TFE with hydro-finishing and TFE with clay finishing

These methods are utilized to segregate oil and foreign components via a TFE, and purify it through hydro-finishing to prevent the secondary pollution. First, the moisture and light oil contained in the used oil are eliminated and then vacuum distillation of free components is required to permit for continuous separation of a TFE. Finally, the oil is encountered to hydro-finishing to eliminate chlorine, nitrogen, oxygen, and sulfur compounds. There is a difference between these both methods, that clay is used for absorption (Kalnes, 1990).

6.5. TFE with solvent finishing

This method is used to segregate oil and foreign substances via a TFE, and request the solvent-finishing with the flow process analogous to TFE with hydro-finishing.

6.6. Solvent extraction hydro-finishing

This method combines solvent extraction and hydro-finishing by eliminating the foreign substances using the solvent and then fortifying oil quality by hydro-finishing. First, the moisture is eliminated and segregated the used oil. Then the mixture of solvent and used oil is encountered to hydro-finishing to eliminate sulfur, nitrogen and oxygen for purification purposes.

6.7. TDA with clay finishing and TDA with hydro-finishing

The dehydrated used oil is vacuum-heated at 360 °C. The ash remains at the bottom, and the oil is divided to 3 types, i.e. vacuum gas oil, base oil (as lubricant) and asphalt residues. Next, the base oil is encountered to hydro-finishing or clay-finishing under high-pressure (10^7 Pa) for continuous utilization (Hamad et al., 2005).

7. Layout some of the various operational processes of industrial and semi-industrial processes in the world

In the regeneration technologies each of the functional processes can be used as a treatment path. The layout of operation processes carry out depending on the quality of product oil and concentration of available contaminants in used lubricant oils (Abdel-Jabbar and Al Zubaidy, 2010). Fig. 2 shows the layout of various processes from regeneration lubricants in the world.

8. Comparison of operational processes of used lubricants in terms of economic and environmental factors

The operating costs and required temperature of acid/clay process is comparatively less than other processes. However, the water quantity required for operating of TDA process is more than other processes. Tables 13 and 14 show the comparison of the various parameters of regenerative technologies (Hsu et al., 2010b; Alhamed and Al-zahrani, 2011; Al-Zahrani and Daous,

Table 14
Regenerative technologies comparison in terms of environmental-friendly (Hsu et al., 2010b).

Regenerative Technologies	Acidic sludge	Residual oil sludge	Hazardous chemical materials	Secondary pollution
Acid/clay	Much	Much	Acid sulfuric	Yes
Distillation	Little	Much	Acid sulfuric	Yes
Solvent de-asphalting	Little	Much	Acid sulfuric and organic solvent	Yes
TFE with hydro finishing	None	Little	None	Few or none
TFE with clay finishing	None	Little	None	Few or none
TFE with solvent finishing	None	Little	Volatile organic solvent	Few or none
Solvent extraction hydro finishing	None	Little	Volatile organic solvent	Few or none
TDA	None	Little	None	Few or none

Table 15
Properties of base motor oils (International Standard DEF STAN 91-43/8).

Motor oil grade	SAE50	SAE40	SAE30	SAE10	SAE5	Re-refined oil	Reprocessing oil[b]
Specific gravity	0.89	0.89	0.89	–	–	–	0.88
Viscosity in 100 °C (Cst)	21.9–16.3	16.3–12.5	12.5–9.3	9.6–7.3	7.3–5.5	9.63	9.5–12.5
Minimum viscosity index	95	95	95	–	–	92	90
Minimum flash point	204	204	200	190	185	234	200
Pour point	−9	−9	−18	−25	−30	−3	–
Color	3–4.5	3–4	3–3.5			1	2.5–3.5
Maximum rate of acidic number	–	–	–	–	–	–	5%
Copper corrosion (100 °C)	–	–	–	–	–	–	0

[b] Base oil quality of reprocessing (acid/clay process).

2000). Table 15 gives a comparative view of the different grades of motor oils and reprocessed oil in terms of their various physical properties. Acid/clay process is increased the PAHs rates of base oil (production) about 4–17 times in compare with obtained base oil of crude oil. The process of vacuum distillation with chemical material-finishing does not decrease the PAHs content unlike hydro-finishing. On the other hand, the process of vacuum distillation with hydro-finishing decreases the PAHs levels drastically compared to that of vacuum distillation with chemical material-finishing process (Al-Ghouti and Al-Atoum, 2009).

9. Management of obtained by- products from the regenerative technologies

According to Table 14 there are some secondary pollutants such as acidic sludge, residual oil sludge and some hazardous waste materials. Also, in the processes equipped to clay filter are produced high rates of cake filter. The filter cake from the filter press can be used in drilling mud. It can also be buried or treated. Metals of filter cake can be used on the basic materials of road (under asphalt road) in road construction operation. The acidic sludge generated was main subject discussed in current study that has been converted to new type of bitumen. Asphalt residues and button residuals of all distillation units can be used to produce different types of bituminous or raw materials for some industries and etc. The organic solvents used in some processes are recovered in the following recycling trend (Bridjanian and Sattarin, 2006). The obtained fuels of regenerative technologies are used so that burning. Table 16 shows the derived fuels properties of used oil as by-product.

The oily sludge generated during the regenerative technologies has hazardous nature (carcinogen). Oily sludge contains various petroleum hydrocarbons, water, heavy metals, and solid particles as hazardous waste materials. Therefore, efforts should focus on the integrated waste management as well as improvement of current technologies (Musee et al., 2008). Hu et al. (2013) showed that some recovery and disposal methods could be used to operate such as, biodegradation, oxidation, stabilization/solidification, incineration, froth floatation, ultrasonic irradiation, electro-kinetic method, microwave irradiation, pyrolysis, freeze/thaw, surfactant enhanced oil recovery, centrifugation, and solvent extraction.

Table 16
Derived fuels properties of used oil as by-product of recovery (MAFF, 2002).

Properties	Unit	Value
Density	15 °C	0.82–0.92
Viscosity	Cst	100–170
Thermal values	kcal/kg	10,277.7–10,694.4
Water	(%)	>3
Sulfur	(%)	0.9–0.5
Lead	PPM	500–1000
Flash point	°C	90–75
Solids	(%)	0.5
Fly ash	(%)	1–14

9.1. New technologies for management of obtained by-products and used lubricant oils

In the classical view, materials can exist in any of the three states of matter such as solid, liquid and gas. But in modern physics, a fourth state called the plasma state has been recognized. Plasma technology may be of two types, natural and manmade. Plasma forces (natural plasma) play a major role in the formation and destruction of celestial bodies like planets and stars, black holes and also influence the earth's magnetic field. Plasmas manmade are being produced in laboratories by raising the energy content of a material, and the energy in question can be any one of the following types—mechanical, thermal, chemical, radiation, rays, electrical, nucleus, energies, combination of them, energies of thermal, mechanical (explosives). Plasma can be present as hot and cold plasma. Plasma technology is a relatively new technology and can be used very efficient for the removal and recovery of hazardous waste materials (in solid, liquid and gas states) in the by-products. Thus, plasma technology may be applied for recycling, eliminating and decreasing the levels of pollutants and toxicity of materials (Jonidi and Hassanpour, 2013b; Hassanpour and Mohammadi, 2012c). Yoon et al. (1999) have reported the processing of used motor oils performed by waste plastics through a tertiary recycling technique (using plasma technology for polymerization) into commercially viable chemicals or fuel oils. Used motor oil contains some paraffinic compounds and it can utilize to provide typical thermoplastics. Therefore, simultaneous processing of combined waste plastics with used motor oils can yield intensive effects and can increase the generation of fuel oils. The uniqueness of plasma processes is associated to the fact that they permit the conversion of an extensive range of organic compounds encompassing important group elements into charged and neutral molecular-fragments and atomic types. These fragments can then fortify surface-functionalization reactions or make macromolecular thin layers up to produce highly and less cross-linked polymers, more highly functionalized films and controlled surface modification. Some of plasma productions are used in medicine, treatment, industries and environmental treatment (Denes and Manolache, 2004).

One of the most important types of hot plasma is the plasma jet. There are several industrial applications of plasma jet reactors, including synthesis (such as SiC, Si3N4, AlN, acetylene gas and etc) of diamond, processes of heating, melting metals, mixed metals refining to separate specific metal, reactive melt, recycling metals, precipitation (mixed metals, metallurgical powder, processed oxide with high conductivity material, ceramic/metal and etc) and coating. Based on the results of the various tests conducted, plasma jet has been reported to be successful in the disposal of municipal solid wastes, heavy metals, fly ash, radioactive waste, industrial wastes materials, kiln dust, solid and liquid organic wastes, used tires, plastics, biomedical waste, chemical wastes, asbestos fibers and products containing PCBs (Gomez et al., 2009; Park et al., 2005; Tong and Reddy, 2006). Thermal plasma is being used in the reformation of natural gas, hydrogen production, fuel cells and hydrogen-rich gases using gasification of industrial synthetics oils and blends of oils, used lubricants and other fuels. Other mentionable uses of plasma technology are the production of waste-derived fuels and alterations in the state of matter from one form to another. Many of hazardous wastes, hydrocarbon-rich sludge can be recycled by plasma technology to give expensive and valuable materials such as diamond and graphite and similar materials. It is predicted that plasmas will also play an important role in the environmental chemistry, in the near future. Production of various organic and inorganic chemical material and durable, biodegradable, non-toxic or with very low toxic materials may soon become a possibility in green chemistry. Plasma technology may also prove to be instrumental in environmental studies. Many of the detection and monitoring systems in laboratories are equipped with plasma tools (i.e. GC chromatography) (Denes and Manolache, 2004; Zhang et al., 2000). Plasmas can decrease the various pollutants levels to several times below their emission standards and can be simultaneously used to recover many of pollutants. Thus, it can be an effective method for reducing the volumes of pollutants to zero. Economic evaluation indicates that this technology can rightfully compete with other technologies, without considering its environmental and technical limitations (Boucle et al., 2005; Foest et al., 2006; Mollah, 2000).

DLC is a hard film which is made from carbon composites and has physical properties like diamond. It also shows very high abrasion resistance and a low coefficient of friction, also it is type of products related to plasma technology. Diamond is formed under high temperature and pressure from bitumen (Chu et al., 2010; Gitis, 2008; Joly-Pottuz et al., 2005). Jonidi et al. (2014) showed that the bitumen 54/130 was produced from acidic sludge and the bitumen may be used for the production of diamond powder or diamond. However, extensive studies and further evidences are required to support this claim (Somasundaran and Zhang, 2006; Hudson et al., 2006). Diamond powder is used as suspensions in organic liquids. To increase the positive effects of lubricants particles and the overall quality of lubricants, small amounts of 0.1% Graphite, less than 1 percent of Diamonds, 1% Titanium dioxide, 5% IF-WS2, 2–0.5 percent CuO, ZnO, ZrO2 and 0.2 percent SiO2, may be added.

The plasma reactor can use two different methods for the production of diamond (Ingelsten et al., 2010). In the first method, diamonds can be produced in the laboratory by the process of HP HT which is essentially a mimic of the natural process of diamond formation. Another laboratory method which can be mentioned in this context is the process of CVD. In this process, instead of using the high pressure, diamond are produced by allowing the atoms to join together to form diamond (Bouchemal et al., 2004). The transfer rate depends on the pressure inside the chamber of deposition. The required pressure and temperature of this process is 1.35 m and 700–720 °C, respectively. Also, in this process a variety of techniques and materials are used, as a source of carbon, hydrogen and activator. The required energy is supplied from heating elements, flame, and microwave radiation. In order to start the reaction, mixture from both of the gases methane and hydrogen to ratio of 1–2% and 98–99% continuously are injected into the reactor, respectively. Using plasma reactor equipped to anode and cathode plates (electrical current) is produced radicals of hydrogen in order to create active radicals of methyl and also develop the C—C bonds in core surface as well as prevention of forming graphite layers. To form a thin layer of diamond on the surface of the core the reactor temperature must be controlled. The results of researches have been reported the growth rate from 0.1 to 10 micrometers per hour using a heating element and if the flame be used as the source of energy the growth rate will grow rapidly up to 100 μm/h, but will not be good quality. Using microwave radiation the required energy and temperatures can be supplied as well as appropriate speed of growth the diamond layer. The growth process is performed at high temperatures that is why the melting point of the core used should be higher than temperature (the temperature of the reactor) to be processed. Commonly silicon used as the core but elements such as molybdenum and tungsten are also used. Source of atoms and molecules can be gaseous, liquid or solid like acidic sludge. We can point out to this type of process as alterations in the state of matter from one form to another by plasma technology (Spitsyn, 2001). The second method, PVD method is used for the production of thin films, with a thickness of less than 100 nm. Recently, this technique has also been used to produce nano-particles. In this method, the target material is vaporized and deposited on target barrier. Evaporation of atoms and molecules can be brought about by heat sources (Anton et al., 2008).

10. Conclusion

The physical arrangement and layout of operation units in an industry depend on the quality of product oil and concentration of available contaminants in used oil. Regenerative technologies used for the recovery of used lubricants are expensive processes. However, the plus points include decrease in the hazardous waste levels and the identical quality of the obtained oil with that of crude oil. Also, the by-products and pollutants of regenerative technologies are least. Newer technologies like plasma technology may become a boon and will hopefully be effectively utilized to remove, recover and decrease the levels of pollutants and toxicity of all pollutants and harmful by-products. Hence, one day, these technologies may lead us towards sustainable development in all levels.

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